ARTS, CRAFTS & THEATER SAFETY, INC

181 Thompson St., New York, NY 10012

VENTILATION FOR THEATERS AND FILM LOCATIONS

One day there was no COVID-19, and the next day it was everywhere. And the world was not prepared for it in many ways. For example, the virus is primarily transmitted through the air and marginal ventilation has been common in theaters and locations for decades. Even when the ventilation conforms perfectly to codes and standards, ordinary heating and air-condition (HVAC) systems cannot handle infection control without significant adjustments.

ASHRAE. This acronym stands for the American Society for Heating, Refrigerating and Air-conditioning Engineers (ASHRAE). They set standards for design, maintenance, and testing building ventilation systems. The most relevant standard for this discussion is ASHRAE 62.1, *Ventilation for Acceptable Indoor Air Quality*.

THE PURPOSE. The ASHRAE 62.1 standard's purpose is stated as follows:

> 1.1 The purpose of this standard is to specify minimum ventilation rates and other measures intended to provide indoor air quality (IAQ) that is acceptable to human occupants and that minimizes adverse health effects.

"Acceptable to human occupants" means providing air that does not result in a significant number of complaints, and "minimizes adverse health effects" means measurable adverse effects in occupants that are related to the poor quality of the air. Unstated in this purpose, but equally important in practice, is saving energy. This puts the emphasis on "minimum" fresh (outside) air to reduce heating and cooling costs and save the building owner or operator money as well.

ASHRAE 62.1 heating and air-conditioning (HVAC) systems accomplishes these goals by drawing a small amount of air from outside of a building into the system and adding it to a much larger amount of recirculated air. Recirculated air is air that has been removed from rooms throughout the building through ducts and returned to the HVAC air handler to be mixed with that small amount of outdoor air. The amount of fresh air is usually under 20 %.

Next this air mixture is adjusted for temperature and humidity, and run through a particulate filter and returned to those same rooms in the building. This cycle is constantly repeated. The speed at which these cycles occur is usually quantified in air changes per hour (ACH)

AIR CHANGES PER HOUR (ACH). The ceilings of most rooms with these ventilation systems have circular or square "diffusers" where this mixture of recirculated air and fresh air comes into the room. And in other locations, usually also in the ceiling, there are grilles or slots through which the room air is returned to the air handler to go through another recirculating cycle.

When the volume of air coming through the diffuser equals the volume of air in the room, one air exchange has been achieved. This does not mean all the air in the room has been replaced because the air flows slowly into the room through the diffuser and mixes with the air in the room.

In other words, it takes many air changes in order to completely replace the air in a room. And the rate at which these air changes are delivered is measured in air changes per hour (ACH). If you do the math you will also see that the closer you approach 100 % replacement, the longer it takes to remove those last amounts of remaining air. And theoretically, you never remove every last molecule. This phenomena is reflected in Table 1 which shows the time it takes to get from 99% to 99.9 % complete replacement. For this reason, is it easier to use the 99 % figure for replacement.

Diffuser

TABLE 1 - ACH EFFICIENCY

ACH	Time (mins.) required for 99 % replacement	Time (mins.) required for 99.9 % efficiency
2	138	207
4	69	104
6	46	69
8	35	52
10	28	41
12	23	35
15	18	28
20	14	21
50	6	8

THE FILTERS. The ASHRAE rating for filters is the Minimum Efficiency Reporting Value, or MERV. And while they were originally developed to control what ASHRAE deemed as ordinary dust, today we have empirical data on the capture efficiency of these filters at various particle sizes.

Only 16 MERV filters categories were developed originally by the ASHRAE. But since even better filters were needed, the standards for high efficiency particulate filters (HEPA) were adopted by ASHRAE for the MERV 17 to MERV 20 filters. These capture essentially all very small particles such as those from some manufacturers' "clean rooms" or the COVID-19 particles.

THE VIRUS. The COVID-19 virus particles are emitted with the liquid droplets created when we sneeze, cough, sing, talk, and even just breath through our noses. The large visible mist and droplets settle to surfaces quickly and are unlikely be drawn up into the ventilation system. But the smaller ones, especially those under 10 microns in diameter can float in the air for long periods of time.

The longer these tiny droplets remain in the air, the more of the water in them evaporates leaving only mucous and other secretions from our lungs plus the virus itself (which is 0.125 microns in diameter). These dehydrated particles of virus and dry secretions can be in the range of 0.3 to 1.0 microns. Some of these particles have been documented to have remained airborne for many hours. One study's tests showed the particles were are still capable of infecting people after 16 hours.*

FILTERS FOR COVID-19. There is evidence from a study in which the virus has been detected on the through-side of a MERV 15 in both air handlers in a hospital** plus a number of cases of viral transmission that can only be easily explained by ventilation system transmission.

That evidence of ventilation system transmission is in the process of being confirmed. And it should be no surprise since COVID-19 is easily made airborne, it survives many hours in the air, and it is small enough to go through many types of filters and HVAC systems.

TABLE 2 - MERV FILTER PARAMETERS

MERV #	0.1 - 0.3µ*	1.0 - 3.0µ*
9	n/a	35 %
10	n/a	50 %
11	20 %	65 %
12	35 %	80 %
13	50 %	85 %
14	75 %	90 %
15	85 %	90 %
16	95 %	95 %
17 (HEPA)	99.97 %	~100 %

*µ = micron

Commonly, MERV 7 to 10 filters that aren't rated for the fine particles are used and only about 10 to 20 % fresh air is usually provided.

If this is true, the following are both facts:

1. The system meets ASHRAE 62.1 and is compliant with the standards.

2. The system cannot protect occupants from exposure to the virus, even if they all wear masks and keep six feet apart.

HOW VIRUS EXPOSURE OCCURS. The reason an ASHRAE-compliant ventilation system can no longer be considered safe for occupants is that the ASHRAE standard is totally inappropriate for controlling a tiny particle generated inside the rooms by the occupants. This tiny airborne particle can travel on air currents all through the room. If the HVAC system provides the typical two ACH, then the air in the room is only replaced 99 % after over two hours. And if the filter is not a MERV 17, the virus can be recirculated back into rooms in the building.

DISTANCING AND CLOTH MASKS. Only the large droplets are likely to settle within six feet in still air. The tiny aerosol particles float on air currents all over the room and around barriers and shields. The N95 masks can capture 95 % of these tiny particles, but the more commonly used cloth masks are only meant to stop the large droplets expelled by the person wearing the mask.

PERCENTAGE OF FRESH AIR. The last piece of this puzzle is the percentage of fresh air added on each cycle. Many HVAC systems provide 10 to 20 % fresh air. This is too low to sufficiently dilute the virus particle in the air. Resetting the HVAC system's fresh air intake to 100 % will provide a high level of protection but can raise heating and cooling costs unsustainably. More reasonable strategies involve raising fresh air in tandem with better filters and more ACH.

AIR TESTING. To prove to occupants that the ventilation is providing enough air for good air quality, building owners or engineers often do air testing. They test for the carbon dioxide that is emitted when people breathe which can accumulate to uncomfortable levels when there is insufficient fresh air. ASHRAE 62.1 limits the amount of carbon dioxide (CO_2) to 700 parts per million above outdoor air levels. But since the source of the CO_2 is people's breath, this test is only valid when the building has a normal occupancy load. Obviously, ALL rooms that are either empty or have a low occupancy due to distancing will pass the CO_2 test even if they are getting no outdoor air whatever. The test is useless in this pandemic.

Tests for particulates are equally useless since particulates are mostly from outside air. During this crisis, outdoor air is "good" air even if it contains pollution particles. We are safer outdoors than in.

HOW DO WE FIX THIS? The operators of the HVAC system must report to users and unions, data on three ventilation parameters:

1. **Air exchanges per hour.**
2. **The grade of the filter in the air handling unit.**
3. **The percentage of fresh air introduced.**

With these three items available, it is possible to calculate a risk reduction estimate and provide employees and other building occupants with the period of time it would take replace 99 % of the air in various rooms. The two major national industrial hygiene organizations are in basic agreement on strategies that should be considered.

1. AIHA RECOMMENDATIONS. The American Industrial Hygiene Association (AIHA) published a guidance document called *Reducing the Risk of COVID-19 using Engineering Controls*, Version 1, on August 11, 2020. It includes a graphic on page four that plots relative risk reduction against ACH (see Table 3). But these calculations are for a system using a MERV 17 (HEPA) filter. This means that the percentage of fresh air is only relevant to comfort since both fresh and recirculated air meet the objective of being virus-free.

TABLE 3
EFFECTIVE ENGINEERING CONTROLS
(for HVAC systems with MERV 17 filters)

AIR CHANGES/HOUR and Other Methods	**RELATIVE RISK REDUCTION**
12 ACH	99.9 % *
10 "	99 % *
6 "	95 % *
4.5 "	90 %
3 "	78 %
1 "	40 %
Face covering for all occupants	10 %
Face covering for CoV positive	5 %
N95 respirators for occupants	90 %

* AIHA rates these levels as highly effective

The "relative risk reduction" is the theoretical reduction of the risk of getting the virus. They show that 99.9% to 95 % risk reduction can be achieved if six ACH and a MERV 17 filter are used. And Table 1 (above) shows that at six ACH, the room is 99 % purged of contaminated air in 46 minutes. And it is these high ACH rates of 6 to 12 that they recommend be used.

The AIHA reports "relative" risk reduction because the absolute risk cannot be known. It is not possible to know if there are no infected people in the room or there are ten. (It is also important to note that face coverings for all occupants only provides an estimated 10 % risk reduction. Distancing also is not very effective against the aerosol.)

This use of the term "relative risk reduction" should serve to remind us that no matter how HVAC systems are run, there are no guarantees. The ventilation reduces that risk by purging the virus from the room in as short a period of time as possible. However, this strategy cannot prevent more virus from being generated by someone who is infected. An occupant working in a room with someone who is infected still may be exposed. Risk can be reduced, but not eliminated.

And the almost 100 % relative risk reduction in Table 3, requires a MERV 17 filter and 12 ACH which can replace (purge) the air in a room in 23 minutes. However, ordinary HVAC systems usually are not able to run with a MERV 17 filter or provide. Some HVAC systems cannot provide 6 ACH and certainly not even higher air changes.

2. ACGIH WHITE PAPER RECOMMENDATIONS. Also in August 2020, the American Conference of Governmental Industrial Hygienists (ACGIH) published their *White Paper on Ventilation for Industrial Settings during the COVID-19 Pandemic.* Their first suggested measure for COVID-19 control (Page 15) is to "Increase outdoor air supply to 100 % if possible, or to the maximum allowed by the capabilities of the ventilation system." If the system is run at 100 %

outdoor air, all of the air coming into the building is outdoor air and virus-free. And if, as suggested in their second bullet point, the ACH are maintained between 6 and 12, then a 99 % purge (replacement) of the air can be achieved in 30 to 60 minutes (see Table 1 above).

The ACGIH's third recommendation is to "Increase the filtration efficiency of the system to MERV 13 or as high as the filter racks and fan pressure drop will allow." But actually, if you are running at 100 % outside air, there is no need to have a filter except for reducing outdoor pollution particulates in the incoming fresh air.

The second recommendation is to maintain the ACH between 6 and 12. The third is to increase the filtration efficiency of the "system to MERV 13 or as high as the filter racks and fan pressure drop will allow." It is clear that the two major industrial hygiene organizations are in agreement. The ACGIH also provides information on the need to modify ventilation systems to meet these needs.

But it is clear that the similarities between the AIHA and the ACGIH recommendations are that:

1. **MERV 13 to 17 filters should be used**
2. **The ACH should be between 6 and 12.**
3. **The more outdoor air the better and even running at 100 % outdoor air when the filter is less than a MERV 17 is recommended**

Unfortunately, most buildings do not have HVAC systems with fans powerful enough to push air through the high resistance of a MERV 17 filter. It may be necessary to operate at the least effective MERV 13 that can only capture 50 % of the particles of 0.3 microns. Then if the ACH are raised to six and as much air as possible is provided, (e.g., 40 % as a minimum) an acceptable relative risk reduction may be achieved. Table 4 provides examples of some minimum outdoor air percentages.

TABLE 4
SUGGESTED MINIMUM OUTDOOR AIR (OA) AT 6 ACH

MERV #	MINIMUM OA
17	20 %*
16	25 %
15	30 %
14	35 %
13	40 %
any #	100 %

* Although the efficiency of the MERV 17 essentially removes all small particles rendering the recirculated air virus-free, 20 % outdoor should still be added for comfort and good air quality.

The values in Table 4 are only minimum suggestions. The ACGIH recommends providing as much outside air as possible. It is also clear that increasing the ACH could theoretically allow a decrease in outdoor air. But it would be best practice to add as much as possible.

Buildings whose HVAC systems cannot achieve at least these minimum specifications in the three recommendations above need to be off-limits for theatrical and film workers.

The only other ventilation system that qualifies a building as a usable workplace is the dilution (or displacement) industrial ventilation system.

INDUSTRIAL DILUTION VENTILATION. Occasionally a building will be, or will contain, a shop, studio, or lab that has a 100 % exhaust industrial system. If the air supply for this system is air from the building they are in, this room evaluated based on the quality of the building air's HVAC system plus the number of ACH provided by the exhaust fans. But if the room has a separate air supply from a make up air unit that brings in and conditions air specifically for that room and if the exhaust fans can provide 6 to 12 ACH for that room, it is acceptable – even preferred.

RECLAIMING ROOMS WITH INADEQUATE VENTILATION. Small rooms, such as light booths, recording or broadcasting studios, and similarly sized rooms with very limited numbers of occupants may be made acceptable by using HEPA (equivalent to MERV 17) air purifiers. These units usually have a label or manual that provides the square feet of room they can be expected to clean. However, that square footage is usually based on the assumption that the ceiling height is 8 feet. Recalculation is needed for buildings with higher ceilings. These devices also tend to form circular air currents around them as the air at the exhaust portal which is under positive pressure seeks the negative pressure area at the intake. Careful observation of the operation of these units and attention to changing filters is also needed.

OTHER AIR PURIFIERS. Not recommended are ultraviolet (UV) filter units, air ionizers, negative ion generators, ozone generators, and other devices that are hazardous to occupants. Ionizers and ion and ozone generators cause particles to drop rapidly out of the air by charging them so that they are attracted to walls, floors, tabletops, draperies, and even to occupants. This might be acceptable for outdoor air pollution particles, but not for an infective virus. The virus particles are still in the room on surfaces where they can be touched or resuspended by air currents. Toxic ozone gas is produced by ozone generators, ion generators, UV lights, and some other electronic air cleaners. It is counter intuitive to add a gas known to cause respiratory irritation to the air at even low levels when there is a potential for exposure to a respiratory virus.

NATURAL VENTILATION. Older buildings may rely on open windows for ventilation. This system will provide ASHRAE-compliant ventilation when the weather is good enough to leave the windows open. But open or closed, windows do not make these buildings acceptable workplaces now. Air can blow in or out of windows and there is no internal system for filtering the air. These buildings should not be used as workplaces during the pandemic.

WINDOW AIR-CONDITIONERS. Anyone who has washed the filter on their air conditioner knows this is only to protect the internal mechanism from dust in your house as it draws air in. The unit draws in room air, passes it over the cold half of the condenser coil, and blows that same air out. The extension on the back is where hot half of the condenser coil can release the heat to the outdoors. Window air conditioners provide no ventilation at all.

UNIT VENTILATORS (UNIVENTS). These units, common in schools, draw room air from the bottom, heat or cool it, and blow that same air out a grille on top. Some are connected to the outside and provide some fresh air as well. The filter is usually not even rated, and a few models (e.g., made by Trane) can be upgraded to use a MERV 7. Even if the unit runs at 100 % outdoor air, it usually provides between 750 and 1500 cubic feet/minute (cfm), an amount unlikely to create more than one ACH. And this outside air is expelled into the room under positive pressure which drives it with its potential viral load into the rest of the building. This is not a solution.

MORE: If there is a system or unit not address or if you have questions about ventilation where you work, contact actsnyc@cs.com.

footnotes:

* Fears AC. et. al. Persistence of Severe Acute Respiratory Syndrome Coronavirus 2 in Aerosol Suspensions. EID. Volume 26, Number 9—September 2020. https://wwwnc.cdc.gov/eid/article/26/9/20-1806_article?deliveryName=USCDC_331-DM35835.

** Horve, Patrick F., et al., SARS-CoV-2 in Healthcare HVAC Systems, medRxiv preprint doi: https://doi.org/10.1101/2020.06.26.20141085

APPENDIX A: WINDOWS

There are two national organizations in the US that set standards and procedures for providing proper air quality and good ventilation for workplaces including schools. These are:

* The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE);
* The American Conference of Governmental Industrial Hygienists (ACGIH); and

These two organizations plus the American Industrial Hygiene Association (AIHA) have issued written opinions about ventilation during the COVID-19 pandemic. None of these three organizations suggested a slightly open window would be sufficient. Only one mentions windows:

ASHRAE: *Position Document on Infectious Aerosols*. April 14, 2020 states on page six:

> Many buildings are fully or partially naturally ventilated. They may use operable windows and rely on intentional and unintentional openings in the building envelope. These strategies create different risks and benefits. Obviously, the airflow in these buildings is variable and unpredictable, as are the resulting air distribution patterns, so the ability to actively manage risk in such buildings is much reduced.

In addition to ASHRAE's opinion, there are practical reasons which argue against the use of windows.

* windows in some public buildings such as schools are cannot open more than six or seven inches due to child safety requirements.
* windows will tend to be closed in cold or inclement weather.
* air can blow in, out, or not at all through open windows depending on prevailing outdoor winds, whether or not there is a door or other opening through which incoming air can pass through the room, and other conditions.

It is clear that open windows are not a reliable source of fresh air.

APPENDIX B: REPURPOSING HVAC SYSTEMS FOR INFECTION CONTROL

Experiences of workers in shops, theaters, and other venues has been that employers and producers often refused to consider changes to the ventilation systems. And some facilities managers who operate these systems tell workers that it is impossible to even determine the ACH.

However, I have been in negotiations with the engineers running old buildings all over the country including one famous very old theater. These ventilation engineers have managed to calculate the ACH and repurpose their ventilation successfully. But rather than rely on my personal experience, below is the advice of the three major ventilation organization:

A) ASHRAE. In the document cited above, the ASHRAE advises operators of "non-healthcare buildings" to follow a list of "modifications to building HVAC system operation..." which includes:

- *Increase outdoor air ventilation (disable demand-controlled ventilation and open outdoor air dampers to 100% as indoor and outdoor conditions permit).*

- *Improve central air and other HVAC filtration to MERV-13... or the highest level achievable.*
- *Keep systems running longer hours (24/7 if possible).*
- *Add portable room air cleaners with HEPA or high-MERV filters with due consideration to the clean air delivery rate (AHAM 2015). ....*

ASHRAE 62.1-2016
4. Class 4: Air with highly objectionable fumes or gases or with potentially dangerous particles, bioaerosols, or gases, at concentrations high enough to be considered as harmful.

5.18.3.4 Class 4 Air. Class 4 air shall not be recirculated or transferred to any space or recirculated within the space of origin.

These two items in ASHRAE 62.1 show meeting the normal recirculating system operating procedures are not appropriate for control of a Class 4 air containing the virus bioaerosol.

B) AIHA. In their document: ***Reducing the Risk of Covid-19 using Engineering Controls***, a diagram on page four shows that when a MERV 17 (HEPA) is used, the "Effective Engineering Controls" require ACH of 6 to 12. In addition on page 8 it says that:

In non-healthcare facilities where occupant density cannot be limited to fewer than 1 person per ~30 ft2 (i.e. 6-foot radius), or there is likelihood that infected persons are present, delivering higher air change rates than 6 ACH may be necessary.

C) ACGIH. Their white paper:AD ***Ventilation for Industrial Settings during the COVID-19 Pandemic***, August 2020, page 16, has a list of "Important Suggested Measures." The second bullet point reads: "Maintain between 6 and 12 ACH, which will provide greater than 99% purge in 30-60 minutes (CDCd, 2019)." And note, they refer to the Centers for Disease Control (CDC) for this recommendation (see: cdc.gov/coronavirus/2019-CoV).

SUMMARY. Clearly ASHRAE, AIHA, ACGIH, and the CDC all recommend upgrading existing HVAC systems and ASHRAE also warns that windows are unreliable.

APPENDIX C: OSHA GUIDANCE

For completeness on this subject, the Occupational Safety and Health Administration (OSHA) ventilation guidelines* are also covered here. But as most of OSHA's actions have been during the pandemic, their ventilation advice was released far too late (November 4, 2020) and the precautions were woefully weak and inadequate. The second paragraph advises:

Employers should work with a heating, ventilation, and air conditioning (HVAC) professional to consider steps to optimize building ventilation. An HVAC professional can ensure that the ventilation system is operating as intended.

Clearly, the HVAC system must not be "operating as intended." It must be altered to disable any automatic on-demand systems, filters must be upgraded, and greater amounts of air provided. The data sheet then lists the following bullet points:

- Encourage workers to stay home if they are sick.
- Ensure all HVAC systems are fully functional, especially those shut down or operating at reduced capacity during the pandemic.

- Remove or redirect personal fans to prevent blowing air from one worker to another.
- Use HVAC system filters with a Minimum Efficiency Reporting Value (MERV) rating of 13 or higher, where feasible.
- Increase the HVAC system¡|s outdoor air intake. Open windows or other sources of fresh air where possible.
- Be sure exhaust air is not pulled back into the building from HVAC air intakes or open windows.
- Consider using portable high-efficiency particulate air (HEPA) fan/filtration systems to increase clean air, especially in higher-risk areas.
- When changing filters, wear appropriate personal protective equipment. ASHRAE recommends N95 respirators, eye protection (safety glasses, goggles, or face shields), and disposable gloves.
- Make sure exhaust fans in restrooms are fully functional, operating at maximum capacity, and are set to remain on.
- Encourage workers to report any safety and health concerns.

The most useful point is the recommendation to use a MERV 13 or higher, but this is only "where possible." Other reasonable suggestions include using HEPA filter units to supplement ventilation and avoiding air currents from fans or other sources.

The precaution to wear appropriate personal protective equipment when changing filters is a good point, but recommending use of an N95 during this work may not be possible depending on supply.

There is nothing in these OSHA guidelines that could be used to compel employers to provide a well-ventilated work workplace.

Footnote

* COVID-19 Guidance on Ventilation in the Workplace, OSHA Alert, November 4, 2020 https://www.osha.gov/Publications/OSHA4103.pdf